CONSTRUCTION OF THE SUNPATH DIAGRAMS FOR PEKAN AREA FOR SIMULATING THE SOLAR RADIATION EFFECTS TO A BUILDING

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ABSTRACT

This thesis deals with the sun is a valuable source that provided to the earth because the sun produce renewable energy and do not pollute the surroundings. However, the sun can create the problem to the population of the earth. Extreme heat produced by the sun radiate directly to the building and may cause lower energy efficiency. This study concentrates on the solar geometry and constructing of sunpath diagram for Pekan Area by simulating the solar radiation that the effect of a building. Pekan, Pahang is taken as my reference location at a latitude 3^{o} 29' North for construct sunpath diagram. There are parameters used for constructing a diagram which is the latitude of the object, declination angle, altitude angle, azimuth angle and hour angle. The sunpath diagram is a way of representing annual changes in the path of the sun through the sky on a single 2D diagram. Based on the sunpath diagram of Pekan Area, shows the altitude angle is highest at the 21st of March in the northern hemisphere, it is also same for September, 21^{st} at southern hemisphere. It is because the sun is directly in line with the equator, it is called as the equinox, where the declination angle for equinox is equal to zero. The equinox occurs when the sun crosses the equator in which day and night are of the same length. Different for in June, 21^{st} and December 21^{st} is a minimum altitude angle at northern and southern hemisphere. The declination angle for both months is the maximum and minimum 23.45^{o} . Summer solstice occurs when northern hemisphere gets more daylight longer than a night, meanwhile winter solstice occurs when southern hemisphere gets more night time rather than daytime. There are many applications for sunpath diagram can be used by architect or engineers. For the example, they can use the sunpath diagram to calculate the solar radiation that radiates the building and how to control. Hence, the sunpath diagram can be used to find the best position for Solar Photovoltaic Cell and Solar Panel, window shading and water solar heating system.

ABSTRAK

Thesis ini membentangkan tentang matahari mengeluarkan sumber yang berguna kepada bumi kerana matahari mengeluarkan tenaga yng boleh diperbaharui dan tidak mencemarkan keadaan sekeliling.Walau bagaimanapun, matahari juga boleh memberi masalah kepada penduduk di bumi. Haba yang berlebihan yang terhasil daripada matahari boleh memancarkan terus ke bangunan dan menyebabkan kecekapan tenaga yang lebih rendah. Mengambil Pekan sebagai rujukan utama tempat iaitu latitud 3^o 29' untuk membentuk kedudukan matahari dari terbit hingga terbenamnya matahari, setiap 21 haribulan dalam satu tahun. Kedudukan matahari ditentukan dengan mengetahui pengetahuan tentang geometri suria dan sudut suria. Ada beberapa asas parameter yang digunakan untuk membentuk kedudukan matahari iaitu latitud sesuatu objek, sudut cerun, sudut ketinggian matahari, sudut azimuth dan sudut jam. Parameter tersebut digunakan untuk membentuk gambar rajah posisi matahari. Berdasarkan gambar rajah kedudukan matahari di Pekan, Pahang menunjukkan sudut ketinggian matahri paling tinggi adalah pada bulan Mac, 21 haribulan dalam hemisfera utara, begitu juga pada bulan September, 21 haribulan dalam hemisfera selatan. Ini kerana, matahari berada di kedudukan sama garis dengan khatulistiwa ataupun ekuinoks dan sudut kecerunannya adalah kosong. Ekuinoks terjadi apabila cahaya matahari sama lurus apabila melintasi khatulistiwa, menyebabkan bumi mengalami kejadian siang malam dalam waktu yang sama lama. Berbeza pula dengan bulan Jun, 21 haribulan dan bulan Disember, 21 haribulan kerana kedua-dua bulan tersebut menunjukkan sudut ketinggian matahri yang paling rendah dalam hemisfera utara dan juga selatan. Sudut kecerunan matahari adalah maksimum 23.45^o dan juga minimum 23.45^o. Pada Solstis musim panas, bumi mengalami siang lebih lama kerana hemisfera utara bumi mendapat lebih cahaya matahari manakala pada solstis musim sejuk, hemisfera selatan bumi mengalami malam lebih lama. Terdapat banyak kegunaan gambar rajah kedudukan matahari yang boleh digunakan oleh arkitek mahupun jurutera.Contohnya, mereka menggunakan kedudukan matahari untuk mengira bilangan radiasi yang menembusi bangunan dan cara mengawalnya.Selain itu, mereka mengunakan gambar rajah kedudukan matahari untuk mencari posisi terbaik untuk memasang Tenaga Suria Fotovolta dan Suria Panel, teduhan tingkap dan juga Tenaga Suria sistem pemanas air

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LIST OF SYMBOLS

β	Altitude angle
γ	Azimuth angle
δ	Declination angle
I_{DN}	Direct radiation
$\hbar$	Hour angle
ℓ	Latitude
ξ	Incident angle
θ	Surface azimuth angle
ρ	Reflectivity
Σ	Tilt angle
n	Total number of days of the year
I_t	Total irradiation
F_{ws}	View factor
α	Wall solar azimuth angle
Ψ	Zenith angle

LIST OF ABBREVIATIONS

AST	Apparent Solar Time
DST	Daylight Saving Time
FKM	Faculty of Mechanical Engineering
GMT	Greenwich Mean Time
LST	Local Standard Time
UMP	Universiti Malaysia Pahang
ST	Solar Time
PV	Photovoltaics

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The sun is closely related to the earth. It not only provides light to the earth, it gives life to the earth. The sun is the brightest star in the Earth's solar system. And not only does the sun gives us light, but is also a valuable source of heat energy. The sun can be considered as the life giver to living things on this earth, because without the sun, many living thing organism would not exist and survive. However, the sun will also create problems for humans. For example, extreme heat produced by the sun may radiate directly into buildings and may cause lower energy efficiency. The earth rotates every 24 hours, and while it rotates give effect on night a day, it also revolves around the sun making one complete revolution in 365 days. There two movements follow a precise characteristics and geometry called the solar geometry, then giving rise to varying solar radiation which changes gradually. The movement of the sun relative to the earth therefore follows precise paths called sun paths and they can be plotted on a diagram called sun path diagram.

1.2 BACKGROUND

The earth rotates about on a fixed plane that is tilted 23.5^{o} with respect to its orbital plane around the sun. The earth needs 365 days to complete one year per rotation around the sun and the earth also needs 24 hours to complete one true rotation or one day around the sun. It is defined as the time taken for the sun to move from the zenith on one day to the zenith for the next day, or from noon today and to noon tomorrow. Thus, the length of

the solar variability is calculated to be a day or 24 hr. Completing a year, a solar day may differ to as much as approximately 15 min. That is the reason why, for a Muslim, Azan time will be different by a few minutes from day to day and from year to year from Subuh to Isya' prayer's time. There are three reasons for this time difference. Firstly, it is because the earth's motion around the sun is not a perfect circle but it is eccentric. The second reason is due to the fact that the sun's apparent motion is not parallel to the celestial equator. The third reason is because of the precession of the earth's axis. The rotation of the earth also causes the day and night phenomenon. The length of the day and night is depends on the time of the year and the latitude of the location. But for Malaysia, being located close to the equator line, the length of the day and night are almost equal, 12 hours a day and night, but with some variation of about 30 min or so.

The path that the earth takes to revolve around the sun is called the elliptical path. However, to be exact, the number of the days the earth takes to revolve around the sun actually depends on whether referring to a sidereal year or solar year. A sidereal year is the time taken for the earth to complete exactly one orbit around the time interval between two vernal equinoxes. Equinoxes happen when the elliptic in the sun's apparent motion across the celestial sphere and celestial equator intersect. During the equinoxes every point on the earth gets exactly 12 hours of daylight, and 12 hours of night time. The earth is tilted 23.5^{o} the sun is at a maximum angular distance from the celestial equator. At the summer solstice which occurs around the 21st of June, the North Pole is pointing away towards the sun at a positive angle 23.5^{o} in the apparent declination of the sun. At winter solstice which occurs around the 21st of December the North Pole is pointing away towards the sun at a negative angle 23.5^{o} in the apparent declination of the sun.

Everyone knows that the sun rises in the east and sets in the west. This phenomenon has always amazed the mankind. The sun certainly brings about interest for everyone to study its movement and behavior especially its position at different times of the days and months during the year. The sun will rise and set from a different point of the horizon and move along different paths across the sky. Expect during the equinoxes, the sun does not rise exactly in the east and sets in the west. They are determined by the

latitude of the locality. Measuring the angle of the sun in its motion across the sky is done by measuring altitude and azimuth angles. Altitude angle is the angular distance above the horizon measured perpendicularly to the horizon. The azimuth angle is the angular direction measured along the horizon in a clockwise direction. The sun paths are different due to the factors such as different local or local altitude, rising and setting position which is based on the time of the year and lastly due to the duration of the day and night. The sun path diagram is a way of representing the annual changes in the path of the sun through the sky on a single 2D diagram.

1.3 PROBLEM STATEMENT

The energy efficiency of a building is highly dependent on the solar geometry, and therefore the solar geometry must be fully understood for any initiative towards improving the energy efficiency of a building. This is especially true for buildings in a hot climate country like Malaysia, where air-conditioning takes up about 60 to 70 % of the total energy consumed in a building.

The solar geometry has many special effects on the earth. The movements of the earth with respect to the sun create unique characteristics to the earth. The rotation of the earth within the 24 hour period gives rise to day and night, whereas the revolution of the earth around the sun with the earth polar axis inclined at a certain fixed angle gives rise to the changing day and night hours as well as the seasonal changes, from spring to summer to autumn and winter, and back again to summer.

With both movements combined (rotation and revolution) gives rise to further implications to the earth, particularly the solar radiation. The rate of this solar radiation changes every hour of the day, and every day of the year, based on the solar geometry. The solar radiation in turn, gives rise to thermal behavior of a building, and for hot-climatic countries like Malaysia, solar radiation is the major contributor to the air-conditioning load of the building or a space.

Using the knowledge and science of solar-geometry, it is useful to construct Sun path Diagrams for any particular locality. From the sun path diagrams, the engineer and architect can determine the positions of the sun from which the building's orientation can be optimally chosen for the highest energy efficiency, together with the window size and possible use in other applications such as the design of window shade or overhang.

It is not easy to find the Sun path Diagrams ready made for the exact location of the Pekan town. This Final Year Project therefore aims at constructing the Sun path Diagrams for Pekan Town, using a computer program and also data are tabulated in Microsoft Excel Office that will be constructed using the solar geometry equations well established now, to help in the design of energy efficient buildings.

1.4 OBJECTIVE

The objectives of this study are:

1. To understand and study of the solar geometry.

2. To construct the sun path diagrams for a Pekan area with a computer programming and also Microsoft Excel Office with the intention of simulating the solar radiation effects to a building.

1.5 SCOPE

The purpose of this study is to study the solar geometry and construct the sun path diagram for Pekan area. This requires knowledge of the equations involved that determine the changing position of the sun with respect to the earth.

Based on the equations identified for the solar geometry, a computer program will be constructed and also calculating the data using equation provided. It is expected that the sun path diagram be plotted by the computer using Microsoft Excel Office.

The sun path diagram has its special uses, particularly in constructing horizontal shaded for windows, in determining the best position and angle for constructing photovoltaic panels, and in positioning solar hot water systems. This will be elaborated in the final part of the report.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter deals with the review of the solar geometry that would give effect on the earth especially toward energy efficiency in buildings and constructing the sun path diagram for any location or latitude. This chapter begins with a general review of explanations such as a simple definition of the key words and finally constructing the sun path diagrams using knowledge of solar geometry. In this literature review, previous works related to this study are discussed.

2.2 ENERGY EFFIENCY

Many engineers try to increase energy efficiency of the building after the building in completely ready. But without realizing it, the solar geometry is one effective initiative for engineers and architects to improve higher energy efficiency level of the building even before construction. Ramly and Hussain (2012) have stated that the main factor of energy efficiency in building design is to create buildings that utilize a minimum amount of energy. Energy efficiency is an important way of reducing carbon emission and possible climate changes as well as to contain the rapid growth of energy consumption in this world, contributing the preventing supply and mitigating the depletion of energy resources as be cited in Santos et al (2012) . The level of energy efficiency for decreasing the total energy consumption is not easily counted or measured. According to Brookes, Herring and Sorrell, increased energy efficiency may increase rather than reduce, energy consumptions. (Santos

et al, 2012). This fact is due to rebound effect caused by reductions in the marginal cost of energy to promote the environments.

The simple definition of energy efficiency considers the relationship between how much the energy is introduced into a process and criteria to be analyzed. Decreasing energy demand at source is not only better in the long term of sustainability, but also in many instances may also endure very little cost (Madomercandy and Haris, 2006). Improving energy efficiency in the building will contribute to the good side of the environment in the future.

2.3 CLIMATE

The climate in Malaysia can generally be described as tolerable in terms of thermal requirements. Pereira, Silva and Turkienikz (2001) has stated that the main strategic control for making adequate is passive solar and shading of solar radiation to local climatic condition. The passive solar and shading of solar radiation especially true for buildings in hot climates like Malaysia where air conditioning takes up about 70% of total energy consumed in a building. Due to Malaysia's orientation located near to the equator plane, Malaysia is a categorized as an equatorial country which being hot and humid throughout a year.

2.4 SOLAR ENERGY

The sun is the brightest star in the Earth's solar system. In order to give our earth light, also gives valuable benefits to living things as a source of heat energy. Without the source of energy from the sun, living things in an ecosystem would hardly exist and survive. Since solar energy is a natural resource that does not require burning the fossil fuels and associated with the gas emission, solar energy is considered as renewable energy. Many developing countries have already implemented these energy resources in order to supplement the energy from fossil fuel. Replacing fossil fuels with renewable energy sources can also improve national security by reducing dependence on imported energy,

hence the increasing focus on solar energy devices for their nonpolluting and renewable qualities has led to the recent interest in sustainability and in green buildings (ASHRAE, 2011).

2.5 SOLAR GEOMETRY

In the thermal or climatic design of buildings, the sun is the most influential. Understanding of solar geometry is one of the best ways to improving the energy efficiency of the building .Before the engineer or architect come up with the design of the building to control solar energy, it is important to understand the solar geometry and the relationship between sun and earth as the sun will directly affect the thermal behavior of the buildings.

2.5.1 ROTATION

The sun has a unique relationship with the earth and gives many special effects to the earth. In a fixed plane tilted at an angle of 23.45^{o}, the earth rotates 24 hours to complete one rotation or sidereal period. The earth's sidereal period will always be 24 hours since the speed of earth's rotation is constant throughout the year. In the course of the year, a solar day may differ to as much as 15 min. For simplicity, the earth completes one rotation every 24 hours based on the solar day and it moves at the rate of 15^{o} per hrs as full rotation is 360^{o}. Because of the sun appears to move at the rate of 360^{o} in 24 hours, its apparent rate of motion is 4min per degree of longitude has been carried out by ASHRAE (2011). The apparent path of the sun's motion across the sky will make the sun produces a daily solar arc at the different latitudes and at the different angles each day. This daily and hourly solar arc is also called the solar path or sun path. The rotation of the earth about its axis also causes the day and night phenomenon. The length of the day and night depends on the time of the year and the latitude of the location.

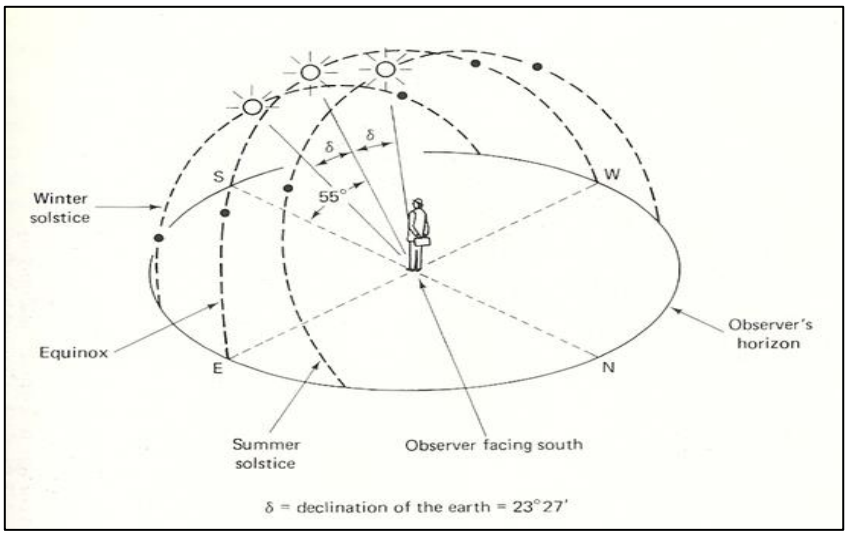

Figure 2.1 different angles of the sun

Source: Retrieved from http://solarwiki.ucdavis.edu/The_Science_of_Solar/1._Basics/B._Basics_of_the_Sun/VI._The_Sun's_Motion (2012)

In Figure 2.1 shows that in the northern hemisphere, the shortest solar day occurs around December 21 which is called winter solstice and the longest solar day occurs around June 21which is the summer solstice. In theory at any time of the equator, the length of the day is equal to the length of the night. In Malaysia, since it is close to the plane, Malaysia equally enjoys almost equal day and night.

2.5.2 REVOLUTION

The revolution of the earth around the sun with the earth polar axis inclined at a certain fixed angle gives rise to the changing a day and night hours occur as well as the seasonal changes , from spring to summer to autumn and winter, and it's back again until summer. It is generally that the earth's complete revolution around the sun 365 days. This path that the earth takes to revolve around the sun in one year is called the elliptical path.

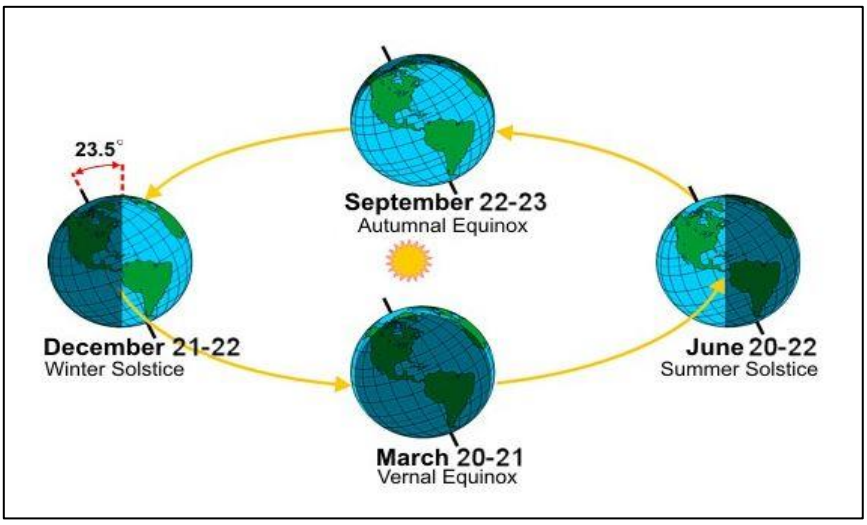

Figure 2.2 Earth's Elliptical Orbit around the Sun

Source: Retrieved from The Fall Equinoxes
http://www.srh.noaa.gov/abq/?n=clifeatures_fallequinox (2012)

In Figure 2.2 shows that the earth makes slightly elliptical orbit around the sun in one year per rotation. The elliptical orbit is formed by Earth's elliptical orbit around the sun. As the earth revolves around the sun, the orientation produces varying solar declination. Equatorial plane is tipped 23.45^{o} from the elliptical plane.

2.5.3 EQUINOX

Equinoxes happen when the ecliptic which is the sun's apparent motion across his celestial sphere and celestial equator intersection. The equinoxes are either of the two times when the sun crosses the equator in which day and night are of the same time length. The spring equinox occurs when the sun moves up from below the celestial equator to above it around the 20th of March. The fall equinoxes occur when the sun moves down from upper the celestial equator around the 22nd of September. The earth experiences 12 hr of a day and a night during the equinoxes and that's how equinoxes get names as equinox mean equal night.

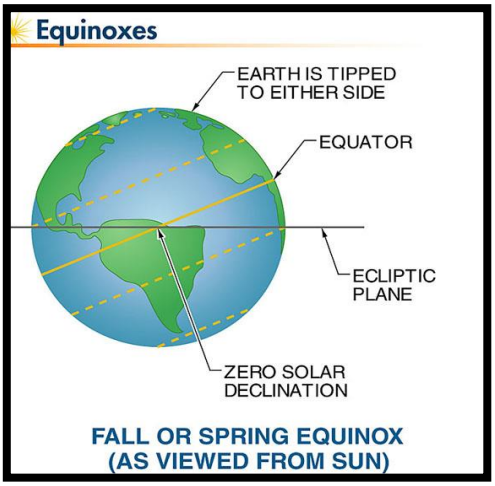

Figure 2.3 Equinoxes

Source: Kothari, D. P. Singal, K. C. and Ranjan, R. "Renewable Energy Source an Emerging Technologies, Reference Book" , New Delhi, 2008

Figure 2.3 shows the equinoxes occurs when the sun is directly in line with the equator. Usually, equinoxes happen on March 21st and September 21st when the sun crosses the equator in which day and night are of the same length.

2.5.4 SOLSTICE

At the summer solstice which occur on 21st June happen when the Northern Hemisphere tip towards the sun at an angle positive 23.45^{o} with respect to the celestial equator. Meanwhile at the winter solstice occur around 21st December when the Northern Hemisphere tip away from the sun at the angle negative 23.45^{o} with respect to the celestial equator. During the summer solstice, the sun travelling higher path across the sky meanwhile the sun path is the low sky during the winter solstice. The duration of the day is longer relative to the night when crossing the sky in the summer solstice.

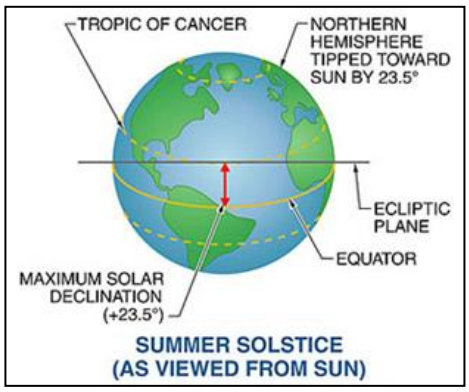

Figure 2.4 Summer Solstice

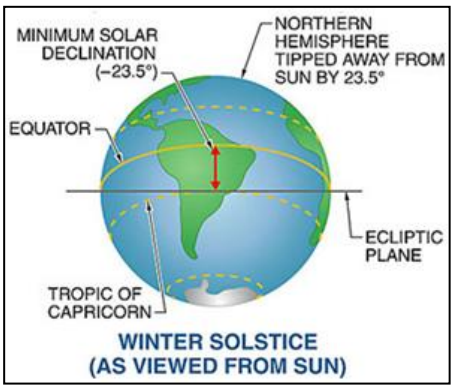

Figure 2.5 Winter solstice

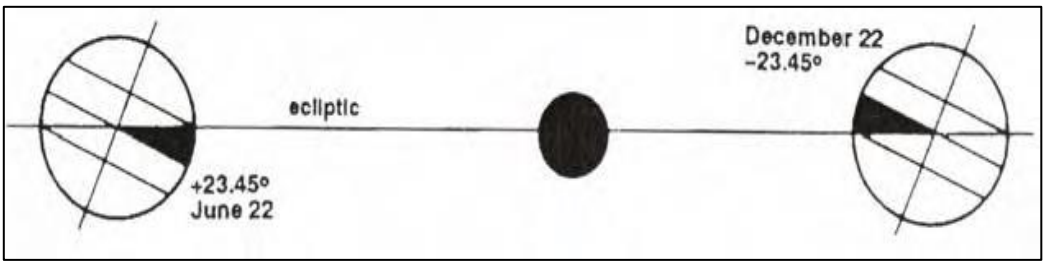

Figure 2.6 Solstices

Source: Kothari, D. P. Singal, K. C. and Ranjan, R. "Renewable Energy Source an Emerging Technologies, Reference Book" , New Delhi, 2008

In Figure 2.4, Figure 2.5 and Figure 2.6 shows that when summer solstice, the Northern Hemisphere tipped toward the sun by 23.45^{o} and get daylight longer than night time. Meanwhile when in winter solstice, the Northern Hemisphere tipped away from the sun and the duration of night longer than day time.

2.5.5 SEASONS

The season is caused by the earth axis which is tilted at 23.45^{o} with respect to the elliptic due to that fact the axis are always pointed in the same direction. The direction of

the sun was pointed in the northern axis, it will be in winter in the southern hemisphere and summer in the northern hemisphere. The sun's ray reached that part of the surface directly and more concentrated when the northern hemisphere is experiencing summer hence enabling to heat up more quickly. The southern hemisphere receiving an equal amount of light ray at more glancing angle, hence spreading out the light ray therefore is less concentrated and cooler.

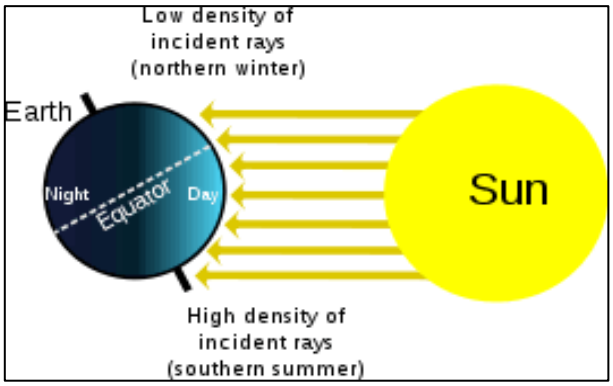

Figure 2.7 Tilt of the earth

Source: Retrieved from http://beyondweather.ehe.osu.edu/issue/the-sun-and-earths-climate/the-sun-earth%E2%80%99s-primary-energy-source (2012)

The Figure 2.7 shows that the sun's ray reached to the surface of the earth directly, it is caused seasons by earth axis.

2.6 SUNPATH

After studying about the knowledge and science of solar geometry, sun path diagram can be constructed at the specific location of orientation. Engineer and architect especially can determine the position of the sun from which the building's latitude from this sun path diagram. Sun path refers to the apparent significant seasonal and hourly positional changes of the sun and length of daylight as the Earth rotates and orbits around the sun.

The sun rises in the east and sets in the west but the uniqueness of this natural phenomenon is the sun is not exactly rises due east and set due west. There are three basic coordinate systems used to predict the solar position such as declination or the positions of celestial object, longitude and latitude of position on the earth and lastly used with time. Hence, affecting the behavior of the sun's lighting and heating characteristic will be effected on the sun path by this latitude and longitude.

2.6.1 LATITUDE AND LONGITUDE

Longitude and latitude are familiar geographic coordinates used on the earth. They are a system of polar coordinates. Longitude is measured from the Greenwich meridian, latitude is measured from the equator. Latitude (ℓ) is the angle subtended by the radial line joining the place in the center of the earth, with the projection of the line on the equatorial plane. Longitude is a geographic coordinate that specifies the east-west position of a point on the Earth's lane. By the longitude and latitude, any position on the Earth's surface can be specified.

2.6.2 ALTITUDE ANGLE AND AZIMUTH ANGLE

After explaining the latitude and longitude, the position of the sun can be measured with reference to the horizon. Measuring the angle of the sun in its motion crossing the sky, azimuth and altitude reading need to be taken. Altitude is the angular distance above the horizon measured perpendicular to the horizon. Meanwhile, azimuth is the angular distance measured along the horizon in a clockwise direction. Zenith angle (Ψ) is the vertical angle between the sun's ray and the line perpendicular to the horizontal plane through the point. For azimuth angle, it started exactly from the north at 0^o and increasing clockwise.